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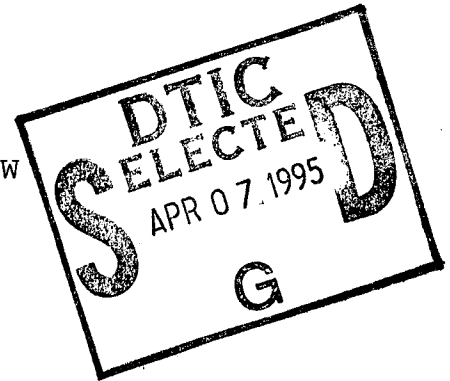
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**TITLE: COORDINATED APPROACH TO BREAST CANCER DIAGNOSIS &
TREATMENT FOR THE MILITARY (BREAST CANCER) CORE**

SUBTITLE: Coordinated Approach to Digital Mammography

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Coordinated Approach to Digital Mammography Report on the Second Year of Project

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1.0 Introduction

There are three components required for the successful development of a digital mammography system: image data acquisition, image processing, and image display and communication. The Georgetown radiology research team has five separate but related grants on digital mammography to address technical issues in a coordinated manner. One of the five grants deals with administrative support functions to four related interactive grants on digital mammography. Detailed individual reports have been submitted to the Army. This report will summarize all four related projects in a concise format. Readers are encouraged to refer to the individual reports for the detailed information. The progress of development of a high performance diagnostic imaging network for digital mammography—I-net 2000—is also included in this report.

2.0 Summary of Tasks

Clinical Optimization of Current Digital Mammography Systems

Digital Mammography Based on Novel Photo Detector

Computer Assisted Quality Control and Telemammography

Implementation of Computer Aided Breast Cancer Diagnosis

Diagnostic Imaging Network 2000

3.0 Coordinated Project Summaries

3.1 Optimization of Current Digital Mammography Systems

3.1.1 Image Processing Optimization

Continued development of image processing optimization for digital mammography was undertaken. Experiments were performed both on storage phosphor and digitized film images. These experiments demonstrated that the conspicuity of small and larger details in geometric test objects could be improved with newer software methods. With newer software methods two effects were noted: first, that smaller objects could be detected than with conventional screen film methods and, second, that those smaller details that could be seen on both screen film and screen film systems were easier to see on the digital methods due to the improved contrast.

During the year we were approached by the manufacturer of new storage phosphor digital equipment to test their new hardware and software to help the company in obtaining FDA approval. Under their grant, we found that their experimental image processing allowed a form of low resolution histogram equalization that could partially correct for the problem we had experienced with the use of the high contrast look up table. The system as given to us, however, also caused small (4-5 mm) masses to be less visible.

We found in working with their software that we could alter it so that it could partially eliminate the detrimental heel effect of the x-ray tube and could preserve the visibility of all objects if set differently than the company had indicated. In running these optimization tests, however, we encountered a software defect that would shut our machine down if we tried to use the software as desired for our tests of digital mammography. This bug does not affect the operations of the machine for the uses the company designed it for, but only affects our work in digital mammography optimization. So far, despite 6 months of negotiations between us and the company, we have been unable to convince the company to make the software modifications to eliminate this bug and to allow us to proceed with our tests. The company also will not, currently, allow us to test this software on digitized film images. We are currently working to write software that will accomplish the same type of result, without infringing on the company's patent and are continuing to negotiate with the company to convince them that this new software would be even better with this bug removed.

3.1.2 Display

Work in developing image processing methods for the display of digitized film mammography has been underway for the past 9 months. The current system allows for the soft copy display of high quality images on 2 x 2.5 K monitors. The system we are working on contains four 2 x 2.5 K monitors and is designed with the concept that a screening mammography workstation would have to be designed differently than the existing MDIS workstation to allow the rapid throughput of these images. Major Donald Smith, MD of Madigan Army medical center has worked closely with us on the conceptual design of this workstation. At its current state of development, the research mammography workstation can display a single full breast image in 0.5 seconds at 2 x 2.5 K. The system provides unsharp masking, high/low and band pass filtering, and windowing capability. We are currently working on improved human interface programs for this soft copy mammography display system. In addition to working on soft copy display, we have printed a few images as laser prints to show its feasibility, but have not yet fully optimized the laser print parameters for digitized film mammography.

3.1.3 Acquisition Of Database

During 1994, 46 proven documented cases (including 14 cancers) were obtained for the project in evaluating the value of film digitization for digital mammography. These cases are kept in a separate file so that they are easily available. Our original research plan had to be modified when we discovered during this year that there were objects seen in these digitized film images of conventional mammograms that could not be seen in conventional screen film mammograms. Initially it was presumed that these were artifacts of the digitization process, but when we compared these to the biopsy specimen radiograph, these objects could in some cases be identified in the specimens indicating that the digitized film mammograms were detecting details not otherwise visible in the original mammogram. To compile the data set for the ROC study and to have a proper "gold standard" of proof, it became necessary to acquire only cases that had high quality specimen radiographs. While this made gathering data more difficult, we now have almost the required number of cases needed for the ROC studies and expect that by April, 1995, we will have sufficient cases with subtle findings to conduct the study.

3.1.4 Tests Of The Suitability Of MDIS Type Display For Digital Mammography

Tests done of the monitor display of digital mammograms and geometric test objects were performed on two different systems, a 1.5 x 2K and a 2 x 2.5 K system. We were unable to create images on the 1.5 x 2K monitor that equaled the conspicuity we could obtain on laser prints of the same data. At this point in time it seems likely that 1.5 x 2K display will not be adequate without zooming the image. We consider zooming to be unacceptable for high volume screening mammography and therefore a large matrix method of display will be necessary. In paragraph 2 we described the characteristics of the display system we are developing. Display on the 2 x 2.5 K system is still at a preliminary stage of testing at our site, but at this time appears likely to be sufficient. We expect to be ready to start the soft copy reading tests of digitized film mammography this summer.

3.1.5 Clinical Test Of Storage Phosphor Mammography

During this year we acquired a contract from the manufacturer of an experimental storage phosphor digital system to test this system to help them acquire FDA approval of their system for digital mammography. This system provides a higher signal to noise ratio than previous systems. These improvements were achieved by improved phosphor chemistry in the imaging plates and improved laser and readout electronics. The image processing software allows a higher contrast look up table than this company's prior methods and also provides a low resolution histogram equalization image processing program. Working under the research protocol for this product we have been obtaining digital mammograms.

We demonstrated images from this machine at the Annual Meeting of the Radiological Society of North American in November-December, 1994, and asked those who wished to give their impression of the quality of the images. We showed comparison images obtained with both conventional and digital methods, using the same exposure levels and in all but one case showing the original conventional mammogram film (one case had an outside initial mammogram and we showed a first copy). 74 people responded. 94% thought that the digital images of the test objects were better, 97% thought they were equal or better. 83% thought the demonstration of microcalcifications was better with the digital method, 88% thought the digital was equal or better. 52% thought the mass demonstration was better with digital method, 77% thought it was equal or better with the digital method. This

preference study does not indicate that the system will improve the detection of cancer, but it is a promising preliminary impression of its potential value.

3.2 Digital Mammography Based On A Novel Photo Detector

A new digital prototype, developed by 3M Imaging Systems based on micro-lithography technology has been installed at Georgetown University for technical and clinical evaluation. The detector system has a multi-layer structure containing a photo-conductor. The latent image produced by an x-ray is stored on the photo-conductor surface, and is then read out by scanning with a high intensity laser beam. The system has both a wider dynamic range (i.e., 2 to 3 order of magnitude) and spatial resolution compared to conventional screen-film and digital systems.

Before conducting the clinical study, the physical characteristics of the system were studied on phantom images for image quality and radiation dose. The evaluation of the 3M system was divided into two parts: (1) system performance for different KVP and mAs, and (2) system optimization for minimum patient dose. The performance of the system was tested on the body part images that are less radio-sensitive than breast images (i.e., extremities). The performance of the system was improved mainly by redesigning the detector structure and using different image processing parameter settings. By the completion of the second year study, the radiation exposure was optimized and the image quality was improved significantly.

3.2.1 System Performance In High KVP

In the first part of the evaluation of the 3M system, the clinical feasibility was studied in high KVP. The focus was on the imaging of extremities, the hip, and the shoulder. The results were compared with those from the conventional screen-film (SF) system. Fuji GF-1/HR-G (50 speed) film was used for extremities exams and Fuji GH-1/HR-G (400 speed) film was used for the shoulder and the hip exams. The high resolution scanning technique and standard resolution scanning technique were used for the 3M system. The experiments were performed for a range of KVP and mAs depending on the 3M system application. Several exposures were used for 3M system's image optimization in comparison with the screen-film system. Source Detector Distance (SDD) was fixed at 40 inches. For hip and shoulder studies the grid was used for scatter radiation reduction. The exposures were fixed for the screen-film, but varied for the 3M system in the preliminary image optimization.

A series of tests were performed on the extremities (hand, foot), the hip, the shoulder, the step-wedge, and the line pair/resolution phantoms in order to evaluate the 3M imaging system's performance in the clinical environment. The optimized (accepted image) images from conventional screen-film (SF) system were compared with the 3M images. Image processing was performed on the 3M images in order to find the preliminary optimum image for comparison with SF images. The images were compared to those taken from SF images and evaluated for clinical studies.

Noise is the major problem at this time for the 3M imaging system and must be reduced before the system goes to clinical trial. The 3M system needs to be optimized for KVP, mAs, charged voltage, and read-out voltage in order to get images comparable to the SF system. Dosimeter is needed to measure the mR amount in the different portions of hip and shoulder. This test will show to a certain extent the radiation dose that will be absorbed by the anatomy and the amount that reaches the plate. We should try to see how much will be gained from image processing. What are the characteristics of the noise? The types of noise influencing the 3M images can result from quantum noise (quantum noise and light photon noise) and fixed noise (structure noise, electronic noise, quantization noise, and other noises). It is important to expose some available mammography phantoms to test the 3M system. This can be done using CD MAM, ACR, and CIRS mammography phantoms for the energy range of 25-35 KVP. This will show us the capability of the 3M system for the lower energy range such as mammography.

3.2.2 System Optimization

The system optimization was performed on the imaging of the extremities. The focus was on finding the optimum technique(s) to apply to the anatomy, specifically the hand and foot, for the best image quality in terms of KVP, mA, and exposure time as well as the exposure dose (mR). The results were submitted to the Institutional Review Board (IRB) for clinical trial for extremities. Clinical study was subsequently approved. Sandwich tests were performed on the 3M imaging system in order to measure the skin dose and absorbed patient dose in the

combinations of the anatomy/cassette/imaging plate. The sensitivity of the system was studied on the image quality and the exposure dose, by systematically and consistently varying KVP, mA, and exposure time.

KVP, mA, and exposure time were varied individually for extremities such as hand and foot. The effect of each variable was recorded and the mR was measured. The images are compared and evaluated for the optimum technique. In this study we would like to use basic image processing parameters available to the machine to see how well the front end device (cassette/imaging plate combination) performs and then use more advanced image processing to improve the image quality of the system.

A series of exams were performed on the extremities (hand, foot), step-wedge, and line pair/resolution phantoms in order to evaluate the 3M system's performance under optimum condition(s). The optimized base line (accepted image) images are those taken from the conventional SF system. Image processing functions was applied on the 3M images in order to find the preliminary optimum image for comparison with SF images. The 3M images were compared for different KVP, mA, and exposure times as well as dose measurement for anatomy/cassette/imaging plate combination(s).

The 3M imaging system has shown the capability of operating in the lower KVP with lower exposure dose as compared to the screen-film system without doing any image processing. The variation of mA in the applicable range of radiography has little effect on the foot and hand images. Noise is still a problem at this time and must be reduced. This hopefully will be done in the next phase of the evaluation. The hand images show that the system can be operated in some optimized condition such as at 55 KVP, 250 mA, 0.02 sec, and 5 mAs or 55 to 60 KVP and 3.2 mAs. The 3M system requires mathematical optimization to insure performance comparable to that of the screen-film system. The standard exposure technique system is capable of producing better images for thin parts of the anatomy than the thick parts.

To get better resolution and better contrast for thick body parts, the 3M system needs to operate at a higher exposure dose than that of the conventional technique. Hopefully the dose can be reduced through mathematical image optimization and image processing. Dosimetry was used to measure the amount of exposure (mR) in the different portions of the anatomy/cassette/imaging plate combination. The experiments have shown to a certain extent how much of the radiation dose will be absorbed by the anatomy, how much will be absorbed by the cassette front face, and how much will reach the imaging plate. We still need to determine what or how much will be gained from image processing. In this study some other filtration is needed and more focus should be spent on contrast enhancement. Using the step-wedge images, the optical density of different steps should be measured. Then a similar H & D curve (for SF system) should be plotted for the 3M imaging system for comparison. This test will show the dynamic range of the two systems. This experiment will be done in the next phase. The physical characteristics of the system will be measured. This includes physics experiments to measure the physical characteristics of the system (MTF, NPS, and DQE).

The radiation exposure necessary was twice that of the screen-film system, and patterned noise still occurred in the images. However, as a result of product redesign, the amounts of noise and radiation exposure required to produce readable images have progressively decreased. Additional improvements are currently being made by the supplier of the equipment. These improvements include improvement in image quality through image processing, different generation of the imaging plate, and optimum exposure technique(s).

3.3 Computer Assisted Quality Control and Telemammography

The project has two goals: the implementation of a computer based program of mammographic quality analysis and control and an evaluation of the feasibility of telemammography. Computer aided quality control will allow the technologist to be informed by the computer whether or not common faults in exposure are present in the mammographic image and indicate to her the desirability of obtaining additional views such as compression spot views or magnification spot views prior to the patient leaving the facility. The evaluation of the feasibility of telemammography will involve the development of appropriate techniques for the transmission of mammograms to a remote site for interpretation and the display of the images on an MDIS type workstation, if that can be shown to be of appropriate quality, and as laser prints.

3.3.1 Quality Control — Obtaining The Proper Exposure

Under and over exposed images of the breast can conceal the signs of breast cancer. Although breast images are photo timed, the exposure resulting can be incorrect because of several factors; the technologist must (1) correctly position the breast in relation to the phototimer, (2) correctly select the position of the phototimer in relation to the position of residual glandular tissue within the breast, (3) correctly select the KVP for the breast composition and thickness and (4) use adequate breast compression. Skilled technologists make occasional mistakes in these tasks and technologists who do mammography less frequently are more likely to make such mistakes.

Assessing the exposure that actually reaches the image detector (film or digital) allows one to estimate the quality of the final image. An image that is underexposed contains less information in regions of underexposure than does a properly exposed image. One can estimate the required exposure by measurement of the information content of images of geometric test objects obtained at varying exposures, convert the data into digital form and measure pixel values. One can then compare the pixel value in clinical images to those obtained in geometric test objects to determine whether the clinical images are in an exposure range that contains full information.

3.3.2 Selecting Required Exposure Level In Screen Film And Digital Systems

During this year work has been done to define the exposure levels within which full information is present in screen-film and in digital mammography. This was accomplished by obtaining images of geometric test objects in both screen film and digital systems and quantifying the information present in the images. These tests showed that there was a range of exposure below which full information was not present. In the screen film images this corresponded to an optical density less than 0.5 OD units or above 2.7 OD units. (The upper range of OD varies with the ambient room light and thus is only an approximate value for clinical use.) In the digital system using storage phosphor technology we found that the information content continued to increase up to exposures 4 times those used for conventional mammography (i.e. if the proper exposure for screen film was 28 KVP at 20 mAs, improvement was seen in the digital system at 28 KVP up to 80 mAs, but additional improvement was not seen at 120 mAs). When the exposure used for digital and screen films images was the same, but selected to be optimal for the screen film image, the digital images could be made to equal the small object detectability of screen film. An interesting finding was that at exposures below the optimal level for screen film mammography, the digital systems performed better than screen film, but still not at the digital optimal level.

Our intent in testing for the optimal exposure range was to provide data for the computer analysis QC program. The ability of the digital system to continue to improve in diagnostic level and even exceed the information content of screen film mammography with exposures higher than screen film mammography makes it difficult to select the level at which a repeat digital image should be recommended. The required exposure level for screen film mammography was made clear by these tests for the screen film system we are now using. As we digitize our screen film images we will determine the pixel values for images that contain full information or less than full information to determine the limits for the computer QC program.

3.3.3 Magnification Spot Views Of Microcalcification Clusters

Magnification spot views are used when small clusters of microcalcifications are present. If the microcalcifications are numerous and clearly malignant, a magnification view is not needed, but when a small number is seen (the number used as the criteria for a magnification view varies among radiologists) such as 3 to 10 microcalcifications, magnification views are often desired. We have been working to develop a program to detect microcalcifications and a separate program to assess by their pattern their potential for being associated with cancer. Both programs incorporate neural networks in the decision processes. The development of these programs receives other support, the application of the microcalcification detection program for image QC is part of this project. The program for microcalcification detection is now functioning with an accuracy as measured by Az of 0.88. Software for improved display of the location of microcalcifications is now under development. Once this software is ready, it will be incorporated into the QC program.

3.3.4 Telemammography

During the year we worked on development of a system for telemammography. May 28, 1994, we successfully transmitted over Internet a digitized film mammogram to a laser printer 900+ miles away. During the remainder of

the year we continued to transmit images to test various components of a digital imaging system.

Our tests of image quality of mammographic display on workstations demonstrated that we could not capture full information in a clinically useful pattern on a 1.5 x 2 K workstation because of a lack of sufficient matrix size. 2 x 2.5 K appears to be necessary. The image processing parameters available on the MDIS workstation were tested and appear likely to be sufficient if a 2 K x 2.5 K monitor was used for display; however, our tests suggest that software beyond that available with the MDIS system may offer additional advantages. Low resolution histogram equalization combined with a higher contrast look up table improves the visibility of microcalcifications in laser prints and may also improve the demonstration of microcalcifications on workstations. We are currently working on such software for workstation display.

The display speed of the MDIS workstation would be too slow for a clinically useful screening mammography system. Because of this, during the year, we have been developing a 4 monitor research workstation to test the capabilities of direct soft copy reading of telemammograms. This is a 4 monitor 2 x 2.5 K system. It has the capability of displaying a 2 x 2.5 K digital mammogram in 0.5 seconds. Current image processing capability includes unsharp masking, band pass filtering and windowing. Currently we are working to improve the human interface programs. The system is currently undergoing testing prior to initiating a comparative test of digital mammograms. Preliminary tests indicate that the system is probably sufficient to demonstrate the smallest microcalcifications probably close to if not equal to the quality of screen film, but further testing is necessary.

3.4 Computer Aided Diagnosis

The accuracy of the computer algorithms for the detection of microcalcifications have been further improved since the initial attempt by Chan et al. We believe that it is important to implement the program in a high speed workstation and conduct a large scale pre-clinical trial in order to evaluate its clinical practicability and limitations. The false-positive rate is still very high for the detection of masses. We are developing a computer program to analyze features of suspected masses. An artificial neural network is employed to classify malignant and benign masses. Because of the need for high resolution of digital mammography, data compression is an important means to facilitate the mammographic image transmission and storage. We have studied some characteristics of the mammograms using gray value splitting and full-frame DCT methods. Effects of the data compression on the CADx in the detection of the microcalcifications were also tested in our preliminary evaluation.

3.4.1 Detection of Suspected Microcalcifications

Microcalcifications in breast cancer are reported to occur with five or more microcalcifications as a cluster in a 1 cm² area [Black 1965, Fisher 1975]. When the digitization pixel size is 50 μ m (using a Lumiscan 150), there are 40,000 pixels in 1 cm² area. To have five detections or pixels (0.0125%) possessing high intensity in the area means that one should set a threshold on pixel intensity approximately 3.61 σ (σ : standard deviation). In one experiment, we used 3.02 σ as the threshold corresponding to a maximum of 50 pixels (0.125% as indicated in Figure 1) due to potential larger microcalcification containing several detected pixels together. Note that a background trend correction was applied to each image block prior to the statistical calculation. The previously detected suspected areas (i.e., 50 pixels) were masked with the mean value in this detecting procedure. This procedure was performed with a 1 cm² template (200 x 200 pixels) by moving 190 pixels per step for each operation and by scanning through the mammogram horizontally and then vertically.

After carefully evaluating twenty-two mammograms containing subtle microcalcifications (only three clustered microcalcifications on three mammograms were associated with malignant process), we found that the use of 3.02 σ for the threshold value was fine except for radiolucent regions (OD > 2.3) where a threshold value should be set at 2.75 σ corresponding to 120 pixels (0.3%) in 1 cm² area. In addition, when a large area was detected (> 30 pixels) then additional pixels corresponding to the area would be granted in the local operation. Our results indicated that all microcalcifications (27 clusters confirmed by biopsy and 126 singles were confirmed by an experienced radiologist) were detected through the above procedure. However, an average of 858 suspected areas per mammogram was obtained (i.e., 99.5% false-positive rate for 100% true-positive detection). This procedure is equivalent to a pre-scan process of a computer-aided diagnosis in the detection of microcalcifications [Chan 1987; 1990]. The important point here is that we have developed an effective computer program that can detect all microcalcifications. It takes 5-7 seconds in a DEC Alpha computer to run a digital mammogram of 4,096 x 5,120 pixels. The suspected areas will be used for the further evaluation of CADx using more strait criteria and in the mammographic image compression

for error handling in the next section.

3.4.3 Adaptive Lossless Mammographic Image Compression

We have developed an adaptive lossless compression scheme for mammograms by combining a high compression method and techniques involving the detection of all suspected microcalcifications to ensure data accuracy in the clinically significant areas. The compression of a $4K \times 5K$ mammogram can be typically reduced to compression of 858 suspected areas. However, we can preserve the maximum data accuracy on clinically significant areas.

The unique point of this work is to add the error-free feature for the suspected disease areas to a compression scheme. No compression artifact shall be observed by an experienced breast radiologist. One must realize that there is no need to digitize a resolution as high as $50\mu\text{m}/\text{pixel}$ except those areas containing subtle microcalcifications. However, the error control feature reduced some degrees of the entire compression efficiency (ratio).

We tested the same twenty-two mammograms and calculated the effective compression ratio. We received effective compression ratio of approximately 29 that indicates that an additional 40% of the compressed data was increased when the error-free feature was added to the compression scheme. Since each 12-bit datum is stored in a 16-bit computer space, effective compression ratio was 38 for current commercial data systems. Because the suspected areas may contain significant clinical information, we believe that the error control feature is necessary and is a cost-effective approach for mammography data reduction.

3.4.4 CADx Algorithm For Classification Of Microcalcifications

A computer vision scheme that can classify microcalcifications in digitized mammograms were developed to help radiologists in the diagnosis of breast cancer. The radiographs of pathological specimen of microcalcifications were digitized using a small pixel size of $21 \times 21 \mu\text{m}$. Regions of interest (ROI) that contained clustered microcalcifications were selected and used as input to a convolution neural network (CNN). The diagnostic performance of the CNN was evaluated by ROC analysis, using the area under the ROC curve (A_z) as a performance index. The CNN achieved an average A_z value of 0.90 for classifying microcalcifications associated with benign and malignant processes. Classification of microcalcifications associated with benign and malignant processes is feasible with the high resolution digitization of mammograms. The convolution neural network appears to be an effective tool in the classification task.

3.4.5 Detection of Masses on Mammograms using an Artificial Neural Network

We evaluated the feasibility of using an error-backpropagation based Artificial Neural Network (ANN) classifier to detect mass regions on mammograms. Regions of interests (ROIs), which included masses and normal breast parenchyma, were manually extracted from a database consisting of 87 clinical mammograms. Texture features based on a spatial gray level dependence matrix were calculated and input into an ANN using supervised back-propagation training method. The data were divided into five groups and different combinations of these groups formed four sets of training data and test data. We evaluated the performance of the ANN with different combinations of input features, numbers of hidden layers, and number of nodes in each layer. Using five input features, one hidden layer with ten nodes, and an output layer with two nodes, we achieved on the average a true positive fraction of 84% at a false positive fraction of 34% with an ambiguity rate of 5%.

4.0 Diagnostic Imaging Network 2000

The mammography problem is an important one for public health. Digital mammography presents special requirements because the data volume required to capture the diagnostic content of a single mammography image (measured in bytes of storage) is substantially larger than that of any other diagnostic image. Digital mammography, however, is a fertile field for the application of artificial intelligence and neural network computing as a diagnostic assistant to the radiologist.

Experience with current-generation PACS has shown that the benefits of digital imaging come at the price of lower diagnostic throughput. This project will focus on technologies which will recapture the lost efficiency and improve accuracy for both screening and diagnosis.

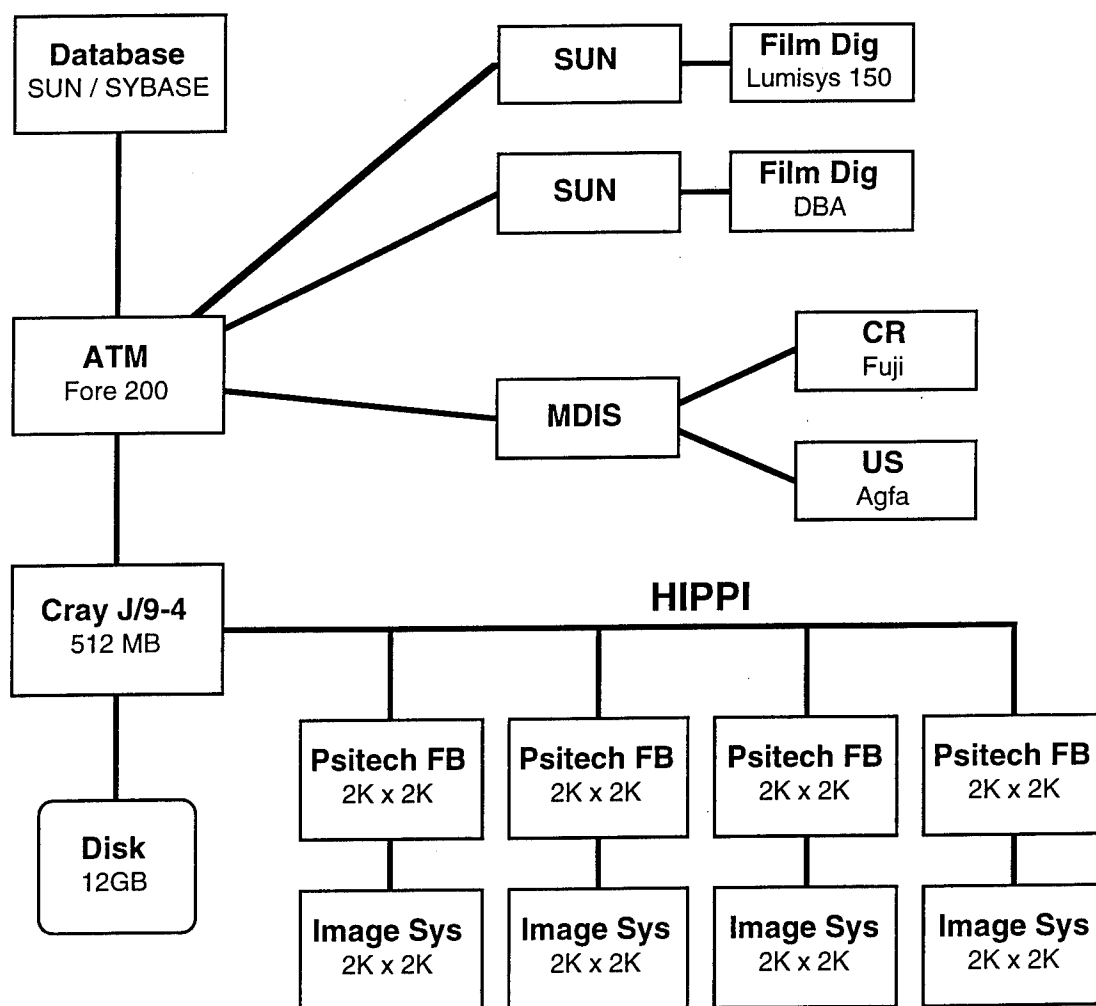
Diagnostic Imaging Network 2000 (I-net 2000) is a project to develop key technologies for the next generation of Picture Archiving and Communication Systems (PACS). The project will develop a system supporting digital mammography for the purpose of investigating:

- intelligent diagnostic agents to identify pathology;
- intelligent agents to classify identified pathology;
- intelligent agents to optimize image presentation, and
- display functions for rapid screening of mammographic examinations.

The system will incorporate:

- acquisition and management of high resolution images from film and commercial digital imaging devices;
- next-generation communications networking;
- computer-aided diagnostic support, and
- specialized diagnostic viewing functions optimized for mammography.

I-net 2000 will be built at the ISIS Center based on the hardware platform diagrammed below.



5.0 Conclusions

The supported projects summarized in this report have continued to progress with promising indications that digital mammography can be clinically implemented at DOD sites by the conclusion of the projects.

We demonstrated that the storage phosphor devices existing at the time of the proposal were not suitable for digital mammography. A newer device using experimental software is currently undergoing tests for the manufacturer and is expected to be sufficient for digital mammography. The acquisition of clinical cases for the evaluation of digital mammography based on digitized film is on schedule and the delays introduced by the lack of proper film digitizers are being rapidly made up now that a replacement digitizer is on site.

The performance of 3M digital mammography system was evaluated based on extremities imaging. The radiation exposure necessary was twice that of the screen-film system, and patterned noise still occurred in the images. However, as a result of product redesign, the amounts of noise and radiation exposure required to produce readable images have progressively decreased. Additional improvements are currently being made by the supplier of the equipment. These improvements include improvement in image quality through image processing, different generation of the imaging plate, and optimum exposure technique(s).

Progress towards the development of a computer based method of assessing the quality of mammography images is continuing with the development of the data needed to assess for proper exposure and for the detection of microcalcifications. We have collected a database of misexposed images that included approximately 50 images and a proven set of 42 cases with biopsy proved breast microcalcification clusters.

Tele mammography has been successfully demonstrated by the transmission of a digitized film mammogram between two sites 900+ miles apart. Additional development for workstation display of transmitted mammograms and for their laser printing still needs to be carried out and an evaluation that indicates whether or not the transmitted images are sufficient for interpretation must be performed. We have acquired an adequately sized database for this evaluation and will be performing the test during the final year of this project.

We have performed mammographical image compression and extended our CADx research. The algorithms of for detection and classification of microcalcifications have been optimized and evaluated based on larger databases. A new algorithm for detection of masses in the diagnosis of breast cancer and an adaptive compression scheme for mammograms are being developed.

We have started the development of the prototype diagnostic imaging network of next generation—I-net 2000—which consists of a high speed network powered by a super computer. This system will support digital mammography that includes intelligent diagnostic agents to identify and classify pathology, optimization of image presentation, computer-aided diagnostic support, and next-generation communication networking. System requirement and specifications have been studied. A Cray super computer and high resolution display hardware have been delivered to the ISIS center. The prototype network is expected to be functioning later this year.